HUECKEL

Methods of Improving The Mississippi River

Civil Engineering

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METHODS OF IMPROVING THE MISSISSIPPI RIVER

BY

WILLIAM CLEMENS HUECKEL

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1908

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WILLIAM CLEMENS HUECKEL

ENTITLED METHODS OF IMPROVING THE MISSISSIPPI RIVER

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

John P. Brooks

Instructor in Charge.

APPROVED: Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering

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OBJECT OF THESIS.

The object of this thesis is to review the improvements that have been made on the Mississippi River, giving their theory, construction and resulting benefits.

DESCRIPTION OF RIVER.

The Mississippi River is the largest of silt-bearing streams. It drains forty-one percent of the total area of the United States, exclusive of Alaska. This drainage area is approximately one and a quarter million square miles and includes the whole of ten states, parts of twenty-two other states and part of two provinces in Canada. The length of the Mississippi proper is twenty-five hundred miles and it has fifteen thousand miles of navigable tributaries. It rises in the northern part of Minnesota and flows almost due south emptying into the Gulf of Mexico. The characteristic feature of the river, especially below Cairo, Illinois, is the succession of long sweeping bends and straight reaches separating them, usually short. The largest tributaries are the Missouri, Illinois, Ohio, Arkansas and Red Rivers. The St. Francis and Yazoo Rivers are dangerous contributors in time of flood.

HEADWATERS. The headwaters of the Mississippi extends from the source, Lake Itasca, to Podegama Falls, Minnesota, a distance equal to about two hundred miles. The River meanders through swamps forming many small lakes in its course. The Northern part of Minnesota contains many lakes and acts as a

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reservoir. Large quantities of water are stored up during the rainy season and is slowly given up during the dry season equalizing the flow of the river to some extent. The river at times is navigable for some distance above Pokegama Falls. From Pokegama Falls to Falls of St. Anthony the valley is quite narrow and there are numerous rapids in this portion. Just above the Falls of St. Anthony there are quite a number of islands.

FROM THE FALLS OF ST. ANTHONY TO THE MOUTH OF THE MISSOURI RIVER. From the Falls of St. Anthony to the mouth of the Missouri River a distance of 712 miles the banks are low, and the oscillations between high and low water rarely exceeds twenty-five feet. In the upper half of this section the river is divided into a great number of sloughs which serve as high water channels, but are nearly dry at low water. The water carries very little sediment and bank erosion is comparative slight. The flow in two places is interrupted by rapids where the bed of the stream is of solid rock. Both of these places have been improved so that they are now navigable. The navigation in the upper portion is usually suspended for about four months of the year on account of the river being frozen.

MISSOURI TO OHIO RIVER. The section of the river between the mouths of the Missouri and Ohio Rivers is the first to take up the enormous load of sediment put into it by the Missouri River. The bank erosion is more noticeable and the banks are higher than in the section above the mouth of the Missouri. The extreme oscillation of the river is thirty-six

feet and the low water slope average is .6 feet per mile. The low water stage commences early in September and continues throgh through the winter months. Sand bars are numerous and their location is constantly shifting. The river washes a rocky bluff a greater part of the distance and at Grays Point it flows through a rocky gorge for seven miles. Near the mouth of the Ohio the normal conditions are often complicated by back water from the floods in the Ohio River, which causes sediment to deposit and which is a great annoyance to navigation.

OHIO TO RED RIVER. Between the mouths of the Ohio and Red Rivers the banks yield readily to erosion. The Ohio River practically controls the flood conditions of lower river. The banks are high but the overflow is frequent, the oscillation between high and low water being fiftythree feet. The sand bars are large in extent. Low water conditions last about a month, the low water slope averaging about 0.35 feet per mile. The greater part of this section has water deep enough at all times for the demands of navigation, many of the bends having depths of one-bundred feet.

THE RIVER TO "HEAD OF PASSES". From the Red River to the outlets into the Gulf the channel is narrow and deep. The banks are moderately stable and sand bars as obstructions to navigation are almost unknown. As far as navigation is concerned there is very little need of dredging or contraction in this section. The extreme oscillation in this part of river is about fifty feet tapering to zero at the Gulf. At new Orleans the depth of the river is generally about 150 feet and has a width

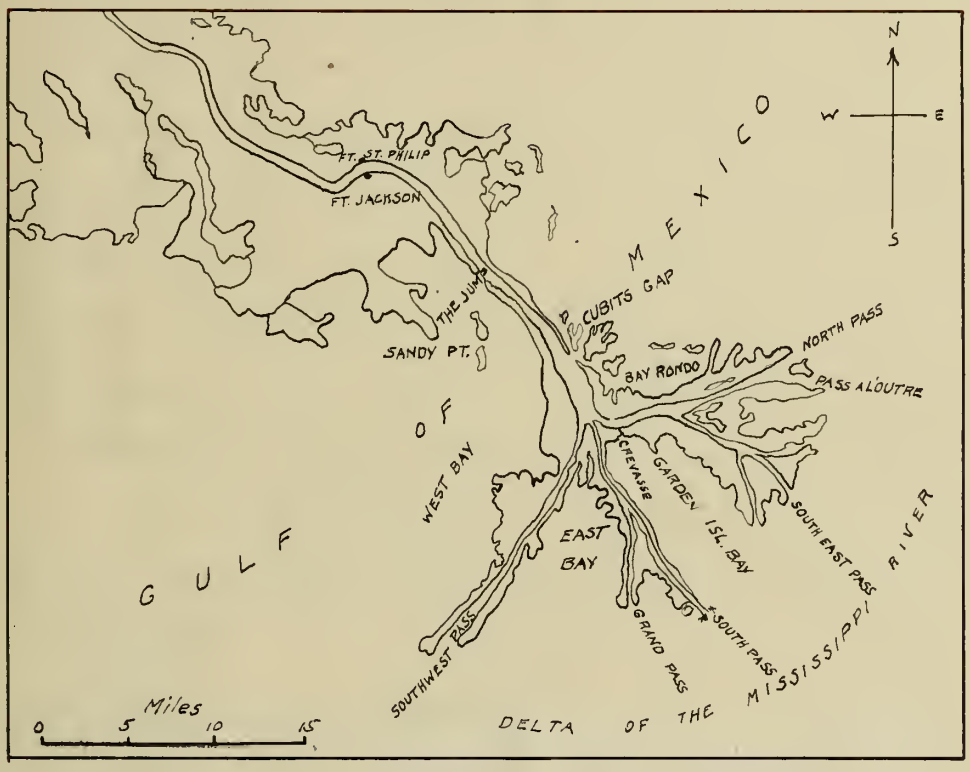
of about one half mile. The depth gradually diminishes and width increases until the point is reached where the river separates into three main outlets and several minor ones. At this point the "Head of the Passes" the river is about 6500 feet wide and thirty-five feet deep.

THE PASSES. The Mississippi River at its conflux with the sea tends to choke itself. The sediment brought down with it, when the backwater of the Gulf is met, is deposited as bars and prevents any considerable depth of channel. As the river has Repeatedly erected dams across the mouth it has simply followed lines of least resistance establishing the three main outlets or passes Pass a l'Outre, South Pass and South West Pass. Each pass is comparatively shallow and wide at the upper end and gradually becomes narrower and deeper in the middle part. Toward the mount they widen again and when lands end is reached all trace of distinct banks are lost and there are bars having a depth on the crest from 7 to 13 feet for a width of about two miles. The advance of these bars into Gulf is at the rate of about 78 feet per year. At the mouths of the passes there is a peculiar phenomenon called "mud lumps" or islands which are pushed up above the surface of the water near the crest of bars and rise sometimes 10 to 15 feet above water and vary in size from a few feet in diameter to a area of 30 acres. They are formed either by a gaseous force or by the pressure of the advancing bar. The material composing them is sticky clay. The tidal wave approaches the mouth from the south-cast and creates currents past the delta from 0.3 feet to 2.5 feet per

second. The winds exert an important influence and they have the character of the north-east trade winds. The flood height is slight and the banks of the Passes are consequently so low that at high tide and high water combined the water overflows the banks for nearly their whole length. These banks are also weak and little is required to produce a crevasse. There are now two notable crevasses at the mouth, Cubits Gap and The Jump. Not all the water at extreme high water reaches the passes, some goes through the Atchafalaya River, some through breaks in levees and some through the Jump, "Cubits Gap" and the minor outlets. Of 1,300,000 cubic feet of water per second passing New Orleans at the time of extreme high water, only about 1,000,000 cubic feet reaches the "Head of Passes".

Cubits Gap was formed in 1862 and has rapidly enlarged. It is now over a half mile wide and carries a volume equal to that of South Pass. The Jump carries about one fourth the volume of Cubits Gap. The following table gives the sizes and discharges of the three principle outlets.

Name.	Length to outer crest of Bar.	Mean width. feet.	Mean depth. feet.	Mean area of cross section. sq. feet.	Proportional discharge.
South West Pass	17	1500	40	60000	41
Pass a l'Outre	15	1900	36	64000	50
South Pass	12	700	34	24000	9



DELTA AND PASSES OF THE MISSISSIPPI RIVER.

IMPROVEMENTS.

OBJECT OF IMPROVEMENTS. The object of the improvements on the Mississippi River is to protect the bottom lands from overflow, to prevent bank erosion and to facilitate commerce. Up to about 1878 they were almost entirely for the protection of the bottom lands from overflow and were built by the states, municipalities and individuals. At this time the traffic on the river had increased to such an extent that more extended improvements were necessary to facilitate commerce. The government took up this work and placed it in charge of United States Army Engineers. Since then the government and the states have spent large sums of money towards improvements.

METHODS OF IMPROVEMENT. The following methods of improving the river have been used; 1. Levees, 2. Dredging, 3. Revetement, 4. Contraction Works, 5. Jetties, 6. Reservoirs, 7. Canals and Locks.

LEVEES.

The most extensive improvement on the Mississippi River has been levees. The conformation of the flood plain renders it peculiarly favorable to protection by them. By the alternative approach and recession of the hills which border it the great plain or bottom is divided into basins which are usually separated at either end from adjoining basins by ridges which are above overflow, and therefore afford points of support for independent levee systems. The object of the levees is not only to prevent the destruction of life and property by floods

but to maintain a navigable channel in low water.

The first levee constructed on the Mississippi River was at New Orleans in 1717. It occupied one of the streets of the city, had a width of eighteen feet, and was used as a roadway. As a general rule the levees constructed up to 1830 were of a smaller cross-section than is the present standard. The average height of levees in Louisiana in 1844 was only four feet. By the time of the civil war, levees extended to the head of the Yazoo Basin. They were insufficient in height and strength and generally too near the bank for safety. In 1874 the floods overtopped the existing levees and did much damage. In 1878 great activity began to be displayed in the construction of levees but the flood of 1882 again played havoc with them Prior to this time all the levees had been constructed by the states, municipalities and property owners along the river.

By the act of June 28, 1879, Congress created the Com-- mission known as the Mississippi River Commission. This commission has supervision of the improvement of the river between Cairo and the "Head of the Passes". This portion of the alluvial basin has been divided into four districts, each of which is in charge of an officer of the United States Engineer Corps. In 1880 the river was first subjected to continuous observation and in 1882 the first direct allotment was made for levees through the Commission. By the act of September 19, 1890 the general repair and construction of levees was first authorized without qualifying restrictions and since thenethis work has formed one of the most important items in the operations of the Com-

mission. Up to date the United States had furnished about one-third of the total cost of the levees. The government had spent $17,500,000.00 and the states and municipalities about $40,000 000.00 up to February 1904. By the acts of 1904 and 1905 two million dollars were appropriated annually for river improvements, one half of which was to be spent for levees. At present there are over 1500 miles of levees on the Mississippi River which is about 71.1 percent of the number of miles needed for a perfect system. The levees are being built two to four feet above the gauge readings of the highest floods and as the system approaches completion it is being made stronger and safer.

The method of preventing floods was settled in Congress after debating for about ten years over levees reservoirs and outlets. Some engineers still advise a combination of levees, outlets and reservoirs for the control of the Mississippi but the reservoir and outlet plans are still in a theoretical stage.

The point on which authorities differ mostly is the cause of the formation of bars during high water. This point alone determines largely the utility of a levee system especially with respect to navigation. The Mississippi River Commission claim that the levees operate to prevent the formation of bars while McMath* believes the contrary is true. The following objections have been made to levees:-

1. They break too easily and often.
2. They raise flood heights.
3. The cost is too much.
4. They cause the river bed to rise because they do

* T.A.S.C.E. Vol. XII, p. 331.

not permit the escape over the bank.

In the resolutions passed by the "Interstate Mississippi River Improvement and Levee Association"* on October 27, 1903, these objections are answered. The following are a few of the resolutions passed:-

1 st. After years of actual observation and experience and supported by the opinions of engineers whether from the Engineer Corps of the Army or from civil life, we desire to affirm that we have the most absolute confidence in the sufficiency of the levee system, when built according to correct standards, to protect the Mississippi Valley from overflow.

2 nd. There was no warrent for the assertion that the effect of levee construction has been or will be to raise the bed of the stream but on the contrary it is our definite conviction that the effect will be to cause a general and considerable lowering of the bed.

3 rd. The Association is opposed to the scheme of reducing flood-heights of the lower river by the construction of reservoirs and so called outlets.

They have based their conclusions on the work of the Mississippi River Commission. Under the direction of the commission an elaborate and careful investigation was made which disapproves the notion that the immediate effect of levee construction is to cause the bed of the river to rise. In 1881, 1882 and 1883 a survey was made of the river bed and another one in 1894, 1895 and 1896. A comparison of these two surveys shows a general tendency to the establishment of a more uniform channel in depth and width and a lowering of the crests of the low water and high

* U.S. Cong. Doc. 58th Cong. Doc. #245.

water bars. The reservoir has been claimed impossible on account of cost and the outlets as impracticable and harmful by the commission.

The effect of the levee system is shown by the following data:-

Year	No. of Crevasses.	Flood swept away miles of levees.
1882	282	54.4
1897	38	8.7
1903	7	2.5

The levee system is not yet complete as it has as yet neither grade section or extension considered necessary for a effective service. In their latest reports the commission favor a complete levee system and are spending their appropriations in building more levees.

The levees along the Mississippi River are plain earth embankments with out puddle walls. The earth found in the Mississippi Valley is sand, clay and loam. The clay is of the blue plastic variety and is the best for levees. The loam is a fine and light soil containing sand and is the worst of the three materials. The advantage which clay has is its resistance to the action of water. In the fourth district, which extends from just below Vicksburg to "Head of the Passes", the alluvium is more compact and tenacious and resists the caving better than in the districts above.

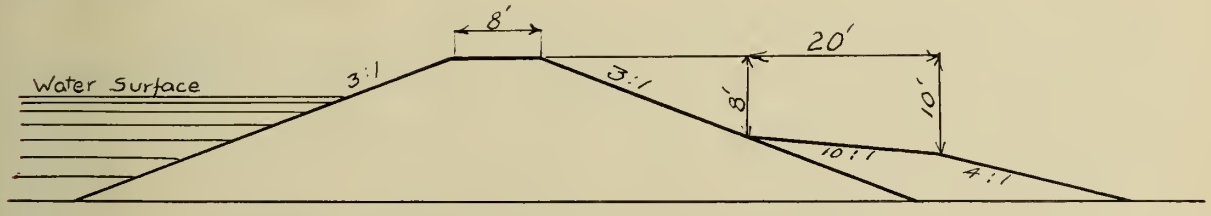
There are two natural conditions predominating in the Mississippi below Cairo which adds materially to the practica-

bility and efficiency of the levee system.

1. The Bermuda grass forms a dense sod presenting great protection against wave wash.

2. The high charge of sediment carried by river at its highest stages. The water seeps through depositing the particles in the interstices of the soil. This gradually diminishes the leakage.

In the 1st., 2nd., and 3rd., districts, which are between Cairo and Vicksburg, the standard levee sections are about the same on ordinary good foundations. The standard dimensions are crown, eight to ten feet; river and back slopes, three to one for clay. If sand or loam is used the dimensions are increased. When the levees are over eleven feet in height a banquette at an elevation of eight feet below top of main levee is added.



STANDARD LEVEE SECTION

The slope of this banquette is ten to one, the width of crown is twenty feet and the back slope, four to one. When the foundation is bad or weak the banquette section and front slope of main levee is increased. The crown of the banquette itself drops one foot in twenty and may be used as a roadway. The height of the levees are built from three to four feet above the highest known flood, some of them having a height of forty feet.

In the fourth district the dimensions of the standard sections adopted vary with the height, and are intended to conform more nearly to supposedly perfect sections. For levees five to ten feet in height, the crown is eight feet, the river slope is three to one and the land slope two and one-half to one. For levees ten to fifteen feet in height, the crown is eight feet, the river slope is three to one and the land slope to within five feet of the crown is four to one, from thence to crown it is two and one half to one. For levees 15 to 20 feet in height the crown and river slope is the same as the above. The first eight feet of land slope from ground is six to one, the next six feet, four to one, and thence to the crown two and one-half to one. The berm of the water side is usually thirty feet.

The foundation of the levees are well grubbed and plowed. A much ditch is generally used, which is a trench excavated near the center of the levee and filled with selected earth and tamped. These ditches are twelve to twenty feet wide and from eight to twelve feet deep. The levees are generally constructed in two foot layers with scrapers and sodded at two foot intervals with Bermuda grass.

The levees have protected thousands of acres of low land from overflow which would have been of no value had it not been for this protection. Crops are now raised in these low lands yearly. The number of miles of railroads has increased enormously in the basins and has helped to improve this country. An example of what the levee has done is shown in the following:

The population in the Yazoo Basin in 1880 was 94672 and in 1890 was 195,346. In 1879 there were 185,868 bales of cotton produced in this basin, while in 1903 this number had increased to 446414.

DREDGING.

Dredging in the Mississippi River is necessary as long as permanent improvements are not completed which will prevent the formation of bars. The Mississippi River Commission is spending annually about a third of a million dollars for dredging on that portion of river over which they have control.

The earliest attempt of dredging on the Mississippi was at South West Pass in 1837. Bucket dredges were tried but they were a failure. During 1857 and 1858, South West Pass was deepened by stirring and harrowing but the results obtained did not warrant the continuation of the work. In 1867 the United States built their first dredge for the improvement of the Passes. This was a stirring and scraping device. Ninty-six thousand dollars was appropriated the same year for the construction and operation of two scrapers or dredges on the Upper Mississippi. Dredging was kept up in the Passes until the completion of the Jetties in South Pass in 1878.

Up to 1891 no considerable amount of dredging was done. The low water conditions of that year, however, emphasized the necessity of temporary expedients for the improvement of navigation. The grain crop was large and the European demand for it was great but the condition of the channel was such that navigation was practically suspended. As a consequence urgent de-

mands were made on the Mississippi River Commission for relief by the temporary removal of crests of obstructing bars. The immediate and economical solution of the problem of deepening the channel was by dredging.

The material in the Mississippi is too heavy, the current is too light and the crossings are two long to obtain satisfactory or even moderate permanent benefits by the use of scraper dredges. The Commission built an experimental dredge which was designed to remove the material bodily and which itself could be moved from place to place. This dredge was constructed in 1895 and demonstrated the efficiency of the hydraulic dredge. The Act of Congress of June3, 1896 was first to formally recognize and require the use of dredge boats and other devices as an adjunct to permanent improvements. A definite project was adopted for maintaining by means of dredges at all stages a channel 9 feet in depth and 250 feet wide. This project provided for the construction and operation of seven hydraulic dredges by June 30, 1900. These dredges have a floating pipe attached which conveys the dredged mass to the bank or swamp section quite remote from the navigable channel. In 1905 the tenth dredge was under construction.

The results obtained by these dredges establish the fact that it is practicable to maintain a navigable channel by means of a suitable equipment of dredges.

BANK REVETMENT.

The purpose of bank revetment is to prevent the caing of banks and thus reduce the load of sediment that is constantly building the bar below; to maintain a normal width and depth in bends; to protect valuable property in danger of being destroyed by the constant action of currents, and also to prevent cut-offs and outlets, and the resulting change in position and flow of river. The caving is of two kinds that caused by abrasion and that caused by the combined action of seepage water and the undermining of the foot of slope by the current, termed sloughing.

The revetment work consists principally in the removing snags, stumps and brush, and the placing of the sheathing for the bank made of willows or plank called mattresses. The work has been of two kinds, the continuous revetment and submerged spurs. The mattresses are placed on that portion of slope extending from deep water to a few feet above the water level and are weighted with stone to hold it in place.

The early revetment work was purely for the protection of property in harbors and not for the general improvement of navigation. Before 1879 the government work on the river was not revetment work proper. These works were more to control and rectify the channels or to close chutes, and consisted of piles, dykes and training walls.

CONTINUOUS REVETMENT. The first continuous revetment work was in 1879 and was only a protection for the bank under low water. It was anticipated that the bank above water would take care of itself. By 1880 it was found that the upper slope.

needed protection, and the banks were then graded to a slope of about 45 degrees and covered with mattresses eight inches thick. These were fastened to the ground by wire tied to dead-men. An example of early revertment work is that at New Orleans during the years 1879 to 1881. This consisted of piles driven in pairs six feet apart along the bank to which were fastened, by large iron rings, light mattresses two inches thick by 25 feet long and 24 feet wide made of fishpole cane sewed together by weaving double wires and afterwards yarn under and over them. These small mattresses were first fastened together forming sections 200 by 24 feet and sunk with iron weights and entirely submerged. They were of little permanent value.

The method of mattress construction was entirely modified in 1882, the "woven matress" type being adopted. The early types were more compact than the ones adopted in 1882 and used up to about 1895, and although the latter was increased in size and given strength adequate to resist all strains it was impossible to weave it sufficiently close and compact to prevent erosive action of the water on the bank through openings in the mattresses at all places. To protect the upper bank from washing away they were graded and mattresses were placed on the slopes. These were built of grillage and brush, bound by poles and wire, covered with rock and connected at the water-line to subacqueous w work. To prevent the damage to mattresses where the action of the current was most violent, and to obtain a structure both stronger and more pliable the fascive form of mattress was tried about 1892. This proved superior to the woven mattress and was

adopted as the standard.

THE CONSTRUCTION OF FASCINE MATTRESS REVETMENT. The banks to receive the revetment are first cleared of timber and debris for a width, on river side, equal to slightly more than three times the height. A pile abutment is then built at one end of the site and to this abutment are moored a number of barges. Other barges on which the matress is made are firmly lashed together end to end and swung out into the stream across the site the mattress is to occupy. These are moored to the pile revetment by drag lines to anchorage along the bank. The greater part of the mattress is willow brush. This brush is loaded on barges and floated to site of the work where barges are swung into position below those on which mattress is built.

In constructing a mattress a head consisting of a bundle of hard wood poles is first made by binding together, with wire, enough of these to form a fascine about two feet in diameter and as long as the mattress is wide. To this head is fastened at intervals of 8 feet, a wire cable and a wire strand. Fascines about 12 inches in diameter are then placed parallel to and against head end held in place by a turn of the wire strand and a clamp on under cable. A second head is placed at a distance of about 10 feet from the first. To these two heads the mooring and shockle lines are attached as well as the cables and wire strand. Lines of poles are also placed longitudinal about 8 feet apart, the full width of mattress to stiffen it and to serve as barriers to prevent stone ballast used from shifting while mattress is being submerged.

The mattress is first ballasted by loading it with rock until the bouyancy is nearly overcome and then sunk by floating barges over it and throwing rock on it in large quantities. After the mattress is down the upper bank is brought to a slope of about 1 to 3 by hydraulic graders, and paved with rock or concrete instead of the willow shore mat, which is destroyed by natural decay in about three years. The cost of the fascine mattress revertment has been approximately $30.00 per linear foot at the most troublesome places.

LUMBER MATTRESSES. Sonce about 1901 quite a number of lumber mattresses have been built. The lumber used is the commonest culls, 4 to 6 inches wide, one inch thick and not less that 12 feet long. The mattress is formed by the weaving of plank over and under plank laid longitudinal about 3 feet nine inches between centers like large split basket work. These mattresses require less bulk of lumber and of stone than brush mattresses, can be built twice as fast and cost less. They have a disadvantage in that they break up worse when piles are driven through them.

SPURS. Submerged Spur Dikes are long cribs placed,at right angles to bank at intervals of about 500 feet and on a mattress. They were first used on Mississippi River in Goulds-boro Bend at New Orleans in 1884. The general construction of these dikes consists of cribs made of willow poles and brush fastened by wires and spikes and having pockets in them in which rock is placed to sink them and having for a foundation a mattress sunk in the channel.

The purpose of this form of revetment is to protect the bank immediately at point they occupy and indirectly to protect the intermediate space by deposit due to eddy and dead water formed by their position relative to swift current of river. The dimensions and general form of crib is governed by the profile of bank immediately at the point where the dike is located.

In bends of great radius and light currents and strong bank material, spurs have proved beneficial and permanent at intervals of 500 feet; but in abrupt bends and light soil, even at reduced distances they are only locally effective and unsatisfactory. In some localities in upper river they have been destroyed or have sunk into pockets formed by the current. At New Orleans they have been used successfully, this portion of the river being especially well adapted to this particular kind of revetment.

The revetment works on the Mississippi are difficult to construct and maintain, owing to the excessive variation in t the height of the water surface and the volume of discharge, the great depth, swift and changing currents, caving bends and the short season when the water is at a sufficient low stage to admit of the building and sinking of mattresses.

No revetment work in the world approaches the magnitude of that undertaken on the Mississippi. Mattresses with a superficial area of seven to eight acres are sunk to bottom of river in depths 80 to 100 feet in currents 5 to 8 ft per second. Similiarly spurs, 430 feet long by 60 feet high containing 80000 feet of lumber, 2000 tons of rock and nearly 20000 pounds of iron are placed in 150 feet of water.

A BIT OF BANK PROTECTION.

SINKING A REVETMENT MAT, ON THE LOWER MISSISSIPPI.

CONTRACTION WORKS.

Low water navigation on the river is improved mainly by the contraction of the channel over sand bars and the closing of chutes by means of dikes and hurdles.

The permeable dikes are placed perpendicular or inclined to the course of river to allow the water to pass through them, offering, however, considerable resistance which causes a reduction in velocity and consequently a deposition of suspended matter. Training walls, parallel to course of river, are used in conjunction with the dikes to prevent the formationo of eddies.

The dikes usually consist of two or more rows of piles driven through mattresses placed at the bottom to prevent scour. The piles are spaced eight to twenty-five feet apart, and the spacing in rows is about eight feet. In the construction of these dikes anchor piles are first driven in the river about one hundred and fifty feet up stream. To these, the first row of piles in the dike are secured as soon as driven. The successive rows are then fastened together by means of cables and braces. The brush screen consists of willows wired to a light wooden frame. After the completion of the dike the anchor poles are pulled up or sawed off below the surface of the water.

The hurdle as constructed at present consists of a row or parallel rows of three-pile clumps spaced eight to twelve feet apart and fastened at the top by wire cables. Where the water is shoal and the current weak a single row of clumps is

A DIKE FOR DEFLECTING THE CURRENT.

usually sufficient; under other circumstances the clumps are staggered in such a way that longitudinal stringers can be placed between the rows to transmit and distribute the strains.

The foundation mattress varies in width from seventy-five to one hundred feet, about thirty-five feet of it forming an apron on the up-stream side. Extra stone is also thrown around bottom of piles where the mattress is broken by driving the piles through it. The ends of the hurdles are protected by T-heads of two rows of clump projecting fifty feet above and one hundred feet below hurdle, the foundation being a mattress one hundred and twenty by three hundred feet.

In time hurdles cause a deposit, on which willows grow and by checking the velocity of high water cause further deposits to be made. The hurdles are generally spaced at a distance of one thousand to fifteen hundred feet.

In a plan for the permanent improvement of the channel by the contraction of its low water width it is now considered settled that the work of bank protection should precede the permeable dikes and other structures of that class, and that the latter may be regarded as supplementary in function and as nec-

essary only in a minority of cases. The greater number of dikes on the river were built between 1880 and 1890 and very few have been constructed in the last few years. By means of the bank revetment the engineers are able to hold the Mississippi rigidly in its channel for the current is thus prevented from eroding the bank, which is the first step in shifting. And, by holding the current in a fixed channel, the same revetment, aided by dikes from opposite shore makes the river scour the channel deep and clear in its fixed position. Up to June 30, 1905 the Mississippi River Commission had spent $11000000.00 on revetment and contraction work, which is 11/47 of the total amount spent on improvements by this commission.

JETTIES.

Prior to 1877 the government had made strenuous efforts, by dredging, to maintain a navigable channel through the bars at the mouths of the passes with very unsatisfactory results. Since then the passes have been kept open for navigation by means of jetties and some minor dredging.

Jetty construction is the building of artificial river banks and have for their purpose the confinement of the channel of the river. The theory of the jetties is that the contraction of the channels increases the current and causes scouring of the channel, giving a free outlet passage.

As early as 1873 a board of United States officers was ordered to report upon the practicability of improving one of the natural outlets. They reported adversely on the jetty plan and

gave as their opinion that the foundation was too unstable and the necessary work too costly and too difficult to build. In February 1874 Captain Eads made a formal proposition to the Government to open the mouth of the river and maintain a deep channel between South West Pass and the Gulf for $10,000,000.00 on the principle of "no cure, no pay". A heated controversy followed, and a board of three military and three civil engineers was appointed and sent to Europe to study jetties. This board reported in favor of the jetty plan and soon after Eads made a second proposition to make a thirty foot channel at South West Pass and maintain it for twenty years. He advocated this pass because he thought that South Pass was too narrow, the bar at its head too difficult to remove and the twelve mile channel, through it, too small for easy navigation. The house passed a bill for South West Pass but the senate amended the bill to apply to South Pass on the ground that it was the line suggested by Army Engineers and the special board. This bill passed both houses on March 3, 1875. The cost of the work was set at $5, 250,000.00 and to be maintained for twenty years at $100,000.00 a year. A channel thirty feet deep and 350 feet wide, was specified, from deep water in the pass to deep water in the Gulf. Through the pass itself and through the shoal at its head the only requirement was a depth of twenty-six feet. The bill was amended in 1879, reducing dimensions of channel, so as to read twenty-six feet in depth and not less than 200 feet wide at the bottom and thirty feet deep without regard to width.

In the location of the jetties the following objects

were aimed at.

1. To give them a direction parallel with the out-flowing current and at right angles to the shore currents along the face of the bar.

2. To give as wide an entrance for vessels as possible and to inclose the natural channel with jetties and thus leave the shoalest water on each side of it in which to construct the jetties and thus lessen cost.

3. To place them at such a distance apart so as to make them secure against subsidence of ground on which they were to rest, that might be induced by the excavation of a channel near them.

The original lines of jetties were parallel and 1000 feet apart and the length of the East Jetty was 11800 feet and West Jetty 7800 feet. The Jetties are built of willow mattresses and stone. The Kipp Dam, 600 feet in length, connects the head of west jetty with west shore.

Each pier of jetties consists of a number of tiers of willow mattresses, two feet thick, each tier being weighted enough by stone to sink it. These mattresses were built on inclined timber ways in 100 feet lengths and then pulled off by a tug and towed to place at the guide piling. Mattresses were sunk one upon another until the surface of the water was reached and the last one was pulled on at high tide. The foundation mattresses were thirty-five to fifty feet wide and seventy-five to one hundred feet long. The whole structure was capped with rip-rap, the uppermost course of which was composed of heavy

stone laid by hand. Later on both jetties were surmounted by a course of concrete blocks built in place for a greater part of the length. These blocks varied from 3 feet 8 inches by3 feet by 16 feet at landward end to 13 feet by 5 feet by 55 feet at sea-ward end, the heaviest blocks weighing over 260 tons. A continuous parapet was built on the East Jetty and consisted mostly of concrete. It was found that the construction of the parapet generated new wave forces which rubble stone or even dimension stone could not withstand. To prevent this action of the waves spur cribs were built and placed 100 feet apart on both sides of jetties, where they were exposed to waves. These cribs were built of Palmetto wood. The end of the West Jetty was closed entirely by crib work for a distance of 300 feet. The end of the East Jetty is more exposed and was more strongly fortified. The East Jetty was given a very flat slope on Gulf and River sides being capped with heavy rubble stone with the usual concrete parapet. Later it was also surrounded by crib work. One year after the beginning of the work (1876) the scour in certain localities was not proceeding with the rapidity desired and it was decided to contract channel between piers at these places by wing dams. These were hastily and flumsily built and consisted of a vertical mattress resting against a row of piles joined by a walling piece. Later these dams were raised to the surface of the water by mattresses laid horizontal.

Since 1880 the principle events in the history of the improvement of South Pass are- 1. The damage done to the concrete capping and parapet of East Jetty caused by storms especially

those of 1882 and 1886. 2. The construction of the inner jetties in 1882, 3. Rebuilding of the concrete walls in 1889, 4. The progressive shallowing of the pass, 5. The continued and enormous accumulation of silt behind the West Jetty, 6. The scour on sea side of East Jetty, 7. The annual subsidence of the works, 8. The advance of the bar into the Gulf.

The inner jetties built in 1882 were constructed inside of the first lines and 800 feet apart for the purpose of contracting the channel and prevent the river water from escaping. The channel was still further narrowed by spur dikes so that clear width is now 600 feet. This construction was found necessary in order to secure the required scour. The inner jetties are composed of two parallel rows of piles driven six feet apart, the space between them being filled up with willows ballasted with stone. These jetties were not intended to resist the heavy seas and there is some leakage through them.

The concrete walls built in 1889 were built on inner side of old wall and on the old mattresses and then covered with stone about two feet deep. This brought the foundation up to the average flood tide and on this was constructed a concrete parapet. The river side of this parapet is vertical, the top width is from three to four feet and the slope of the seaward side is one to one and the height averages three feet. This m new wall has passed through several severe storms without damage. Dikes have been constructed at the head of the Pass and a mattress sill across both South West Pass and Pass a l'Outre for the purpose of diverting the water into South Pass as the volume of

water was thought to be too small for scouring purposes.

A depth of thirty feet has been sustained at government expense, since the expiration of Eads contract, with the help of dredges. All the vessels have used this pass as an outlet to the Gulf. Twenty years ago a thirty foot passage was considered sufficient, today this requirement is exceeded for the larger vessels. Vessels of the greatest carrying capacity and offering the lowest freight rates have been shut out of the river by lack of water over the bars. Delegation after delegation appeared before the House Committee of Rivers and Harbors appealing for a new channel through South West Pass and on June 19, 1902, Congress authorized the improvement.

These jetties are larger that the old ones at South Pass. They are parallel walls about a half mile apart and four miles long. In locating the jetties the same general considerations were taken into account as the South Pass Jetties.

The general construction of these Jetties is similar to these in South Pass. The process of construction consists of building up of tiers of willow mats firmly held in place by rock ballast, and frames of wood. Within these wooden frames of yellow pine, willows are laid. On top of this the concrete capping is placed. This capping is 12 feet wide on the bottom and 8 1/2 feet on top and 4 1/2 feet in thickness. The foundation mattresses are 150 feet wide, a width equal to three to four times that of the mattresses under the South Pass Jetties. This increase in width is to guard against some of the evils experienced in those constructions due to scouring. The mattres-

ses are built in lengths of not less than 200 feet and are from two to five tiers deep, according to the depth of water. In course of time the bottom tiers will sink into mud and the whole structure, by virtue of the immense amount of ballast will become as firm as the natural banks of the river.

On January 5, 1908 the jetties themselves were completed after four years work. All that remains yet to be done is some minor dredging in and about the channel. The contract date is May 21 st, 1908. Up to the present time they have produced the minimum depth of thirty five feet and a width of 1000 feet.

RESERVOIRS.

At the headwaters of the Mississippi River reservoirs have been constructed. This system of reservoirs, which is above St. Paul, is operated by impounding the waters in excess of the natural low-water flow at all times when this excess is not needed by navigation, and releasing it during the low-water navigation. The gauge at St. Paul is maintained a constant height as high as the available water in storage will permit. They have been constructed by the Government primarily for the benefit of navigation and incidentally to control or prevent the floods.

The work of the preliminary survey for the system of reservoirs was begun in 1881. The land in the region was largely the property of the government and therefore little trouble was experienced in making use of it.

On account of the flat country the reservoirs are shallow and of large area. Five reservoir dams have been con-

structed to date, the one at Winnibigoshish Lake, completed in 1884, being the first. It has a reservoir capacity of forty-five billion cubic feet. The dams at Leech Lake and Pokegama falls were built in 1884 and have reservoir capacities of thirty, and four and seven tenths billion cubic feet respectively. The dam in Pine River, a tributary of the Mississippi, was completed in 1886 and has a reservoir capacity of seven and one-half billion cubic feet. Sandy Lake reservoir was completed in 1895 and holds about two billion cubic feet of water.

These dams, when first constructed, were earthen embankments with a water tight diaphragm made of sheet piles driven along the axis or middle line. Another line of piles was driven at foot of upper slope and another at foot of lower slope. The part through which the water was discharged was simply wooden crib-work supporting a lot of sluice ways at the bottom, which are closed with vertically moving slide valves operated by hand machinery on top.

By 1898 the pine timber in the Winnibigoshish Dam had become so rotten that the timber dams were unsafe. A general deficiency act was approved July 7, 1898 and authorized the renewal of Lake Winnibigoshish and Leech Lake dams. The reconstruction of the Lake Winnibigoshish was completed in 1900, all the timber parts being replaced by concrete or masonry. The project at present is to replace all the present timber structures by dams of concrete or masonry.

Without the addition of the stored waters from the reservoir system, the river at St. Paul is liable to fall to

a stage of 0.2 feet as happened in July 1894 where as with judicious and economical use of the reservoir waters it is quite practicable to keep the gauge at St. Paul from ever falling below 3 feet. This is a great benefit to navigation at St. Paul and below. Its influence reaches as far down as Dubuque where a raise of 3 inches has been observed by Signal Service officers. On the 424 miles of river above St. Paul a still greater effect can be obtained. At present few steamboats go above St. Paul, owing to obstructions occasioned by the logging industry. There is much local opposition to the "Reservoir System" in northern Minnesota due primarily to the fact that much land is necessarily overflowed around the edges of reservoirs, the country being rather level.

Reservoirs have been proposed, by some engineers, for the basin in lower Mississippi Valley but the Army Engineers have not favored them. They claim that by means of other forms of improvements, such as levees, dikes and revetments, the required results may be obtained without inundating large tracts of land for reservoir sites.

The benefits of the Upper Mississippi Reservoirs are as follows:-

1. They prevent floods or reduce the intensity of them.
2. They furnish a sure supply of water for navigation during the low water season.
3. They provide a more nearly uniform distribution of water for power purposes.
4. They furnish water for irrigation purposes.

5. They prevent the pollution of water used for domestic purposes during low water.

CANALS AND LOCKS.

In several cases canals have been constructed on the Mississippi River in order to enable boats to pass the rapids.

The rapids above Keokuk, Iowa are passed by means of a canal with eight miles of slack water navigation and three locks with a total lift of eighteen feet. The Desmoines Rapids Canal affords a draft of five feet at extreme low water. There are three locks having an available length of three hundred and twenty-five feet and width of seventy-eight and one half feet.

CONCLUSION.

The United States Army Engineers have made extensive and beneficial improvements on the river, but they have been limited in their work to the appropriations made each year. Here and there they have developed stretches of ample deep and safe channels and such stretches are usually where some of the worst obstacles existed originally.

They have learned how to do things that no engineers had ever attempted before. Many expedients have been tried, some of them of their own design and some of them copied and enlarged from foreign works. A special type of bank protection has been developed. When the river is completely reveted it will cover every bend into which the current sets, 600 miles in all between Cairo and New Orleans. When this is done it will not only provide a clear channel but in addition will give a safe

bank for the farmers, back of the river, a safe foundation for levees and will make land in the valley which is now worth $20.00 an acre worth $150.00 or more. The engineers have learned more than revetment, they have learned to direct or concentrate the flow of the river by the use of light dikes. They have also studied the reservoir systems and have developed them to some extent upon the Upper Mississippi.

It has always been cheaper to carry freight by water than by rail but it is very true that a vessel aground will frighten more freight off a river than a dozen railroad wrecks will frighten from a railroad. A movement has lately come about in the Mississippi Valley to rebirth the water transportation in the valley as it was before the time of railroads. The people are demanding a fourteen foot channel through the valley,not on the Upper Mississippi unless we can enlarge the reservoir system or use slack water there but from the Great Lakes to the Gulf, from Chicago by way of the Illinois river. President Roosevelt on his trip down the river in October 1907 declared himself in favor of the fourteen foot channel and in his message to Congress made it plain that the improvement of the Mississippi is as important a work for them as is the Panama Canal.

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